Rocket Development Test Cell J-4

- ***Vertical orientation***
- ***100,000 feet simulated altitude***
- ***48 feet diameter x 125 feet high***
- ***1,500,000 pound max thrust***
- ***250,000 data samples/second (aggregate)***

Rocket Development Test Cell J-4 is a vertical test cell designed for testing large liquid-propellant engines or solid-propellant rocket motors and entire propulsion stage systems at simulated altitudes up to 100,000 feet. The test facility has a design limit of 1,500,000 pounds of axial force; however, support equipment in its current configuration limits the measurement capability to 500,000 pounds of axial force and 50,000 pounds of side force.

The test cell is equipped with a temperature-conditioning system designed to maintain the test article at a prescribed temperature from 50° to 110°F (± 5°F). The facility is uniquely suited for vehicle integration tests because of its large test cell volume. The test cell has a 48-foot basic diameter with an available capsule height of 82-feet which can be extended to a maximum height of 125 feet by the addition of 43-feet spools. The test complex also includes a large volume dehumidification chamber (100 feet in diameter by 250 feet deep).

Rocket Development Test Cell J-4

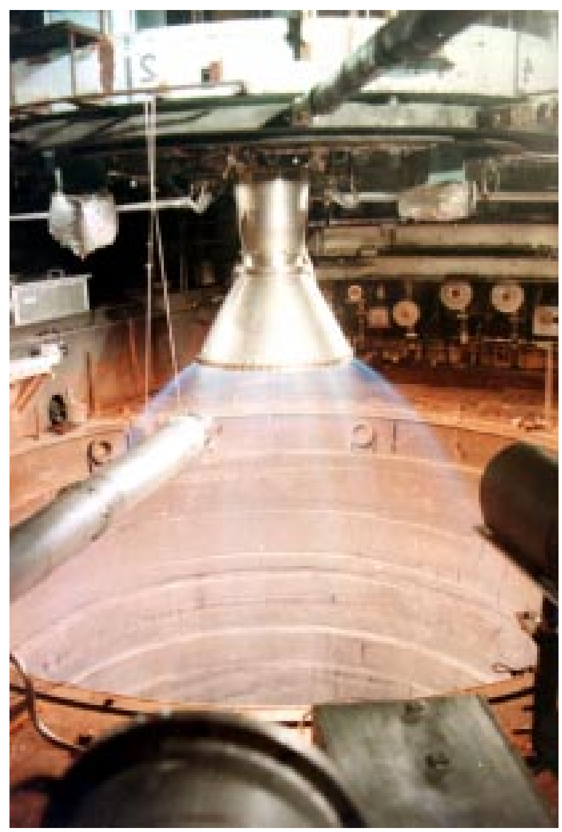
Test capabilities of the J-4 test cell facility include:

- long duration altitude (mission duty cycle) testing
- testing of high-area-ratio nozzles
- simulated altitude performance testing
- ignition performance testing
- nozzle development testing
- stage separation tests
- heat transfer effects and post-test heat soak testing
- vibration and dynamics testing
- failure analysis (propellant extinguished) testing
- vertical spin testing

AEDC has recently installed a hypergolic (AZ50/NTO) propellant system which was used to test the Titan IV LR-91 engine and a cryogenic (LOX/LH2) propellant system.

Due to the large size of the facility, J-4 is uniquely suited to accommodate an extensive suite of state-of -the-art diagnostic instrumentation. AEDC has demonstrated these diagnostic tools, which include laser fluorescence, infrared and ultraviolet imagery, high-speed video, and real-time radiography, to verify system performance and structural integrity and characterize plume signature phenomenology and flowfields.

AEDC has tested a number of liquid-propellant engines in the J-4 cell, including the LR-91 (Titan II/III), LR-87 (Titan IIIC), J2 (Apollo/Saturn), J2S (Post-Apollo), RL-10, and TR-201. Solid-propellant rocket motors tested in J-4 include the Peacekeeper Stage II, Minuteman Stages II and III, Trident Stage III, Super BATES, Small ICBM Stage II, and STAR 27 and 13A motors.



A storable liquid rocket engine firing in support of plume characterization experiments in the J-4 Vertical Altitude Simulation Chamber.

Rocket Development Test Cell J-5

- ***Horizontal orientation***
- ***100,000 feet simulated altitude***
- ***16 feet diameter x 50 feet long***
- ***125,000 pounds max thrust***
- ***250 data samples/second (aggregate)***

Rocket Development Test Cell J-5 is a horizontal test complex designed primarily for static testing of solid-propellant rocket motors with up to 125,000 pounds per foot thrust at simulated altitude conditions of up to 100,000 feet during firings and 140,000 feet for static conditions.

A test cell auxiliary pumping system is available for increasing test cell altitude and/or for removal of gases liberated in the tests cell capsule by gas generators, thrust vector control subsystems, and thrust termination devices.

The test cell is 16 feet in diameter and 50 feet long, and is equipped with a temperature-conditioning system designed to maintain the test article at a prescribed temperature within a range of 15° to 110°F (± 5°F).

A multicomponent force-measuring system provides precision ballistic data capability in the range from 0- to 127,000 pounds per foot axial, 22,000 pounds per foot yaw, and 75,000 pounds per foot pitch force. The axial thrust abutment and load train are rated to 300,000 pounds per foot.

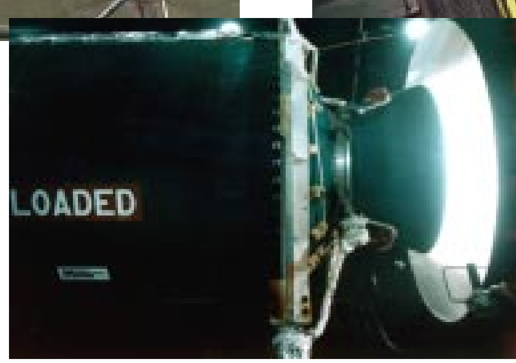
The remotely controlled binary deadweight axial calibrator used with load cells within its range can select any force level from 0 to 127,000 pounds per foot in increments of 1,000 pounds per foot. Pitch-, yaw-, and roll-force columns are equipped with laboratory-calibrated load cells. The test cell can incorporate a flexure-mounted spin fixture to test motors under the combined effects of simulated altitude and rotational spin (up to 250 rpm, depending on motor weight).

Test capabilities of the J-5 test facility include:
- long-duration altitude tests
- launch pressure profile tests
- testing of high-area-ratio nozzles
- altitude performance tests
- ignition performance tests
- spin testing
- nozzle development testing
- stage separation testing
- heat transfer and posttest heat soak testing
- vibration and dynamics testing
- failure analysis (propellant extinguished) testing

Solid-propellant rocket motors tested in J-5 include Scout, Castor Stages II and IIA, Minuteman Stages II and III, Athena Retro, Titan III subscale, five- and seven-segment stages, Poseidon Stage II, inertial Upper Stage (IUS), Improved Performance Space Motor (IPSM), Peacekeeper Stage III, PAM-DII, Intelsat IV, Small ICBM Stages II and III, SDI ORBUS, STAR 37 and 63, and solid propellant gas generators, as well as various demonstration motors.

Aerial of Rocket Development Test Cell J-5.

J-5 support space systems payload systems such as (IUS, PAM D-11 and STAR).



Minuteman Stage III in J-5

Large Rocket Development Test Cell J-6

View from the J-6 Dehumidification Chamber of the J-6 Test Cell Building and Interchangeable Exhaust Diffusers.

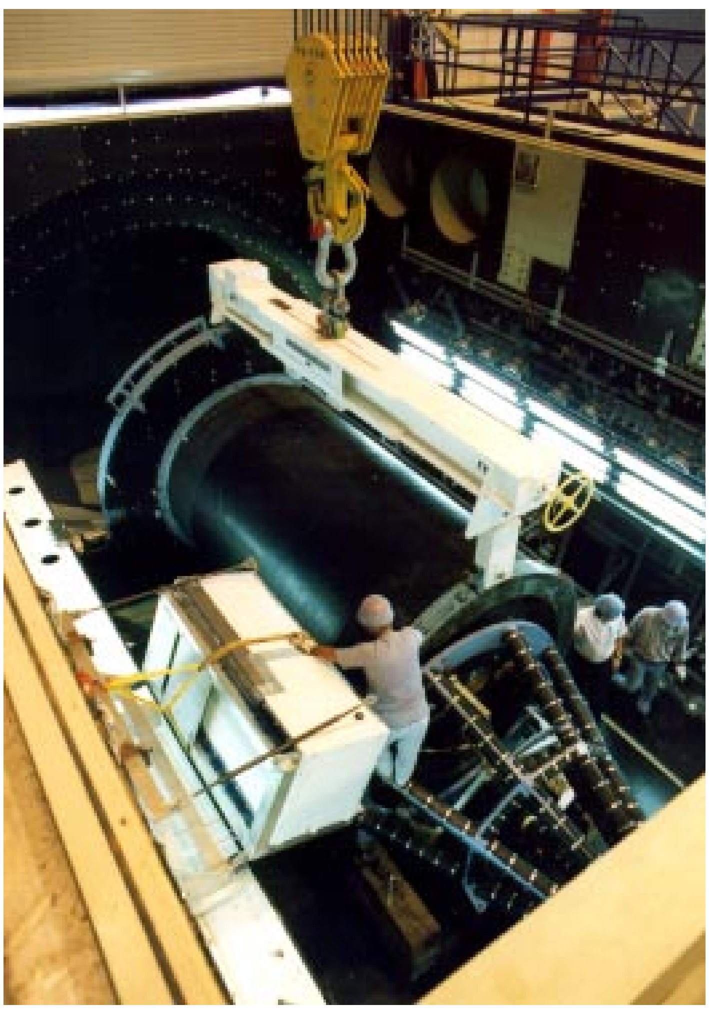
- ***Horizontal orientation***
- ***100,000 feet simulated altitude***
- ***26 feet diameter x 62 feet long***
- ***500,000 pound max thrust***
- ***250,000 data samples/second (aggregate)***

J-6 is designed to test large detonable solid-propellant rocket motors with up to 80,000 lbm of class 1.1 propellant.

J-6 is located more than one-half mile away from other AEDC facilities to eliminate the potential for damage in the event of an explosion. The cell can accommodate testing motors with up to 500,000 pounds thrust at simulated altitudes of 100,000 feet. The test capsule is a cylindrical section 26 feet in diameter and 62 feet long. The temperature-conditioning system can maintain the test cell air temperature at a prescribed temperature within the range of 15º to 110ºF (± 5°F) from motor installation until prefire pumpdown at altitude conditions.

In addition, the dehumidification chamber can be used as a 250-foot-diameter by 100-foot-high concrete vacuum bottle, and would be ideally suited to support special testing associated with space vehicles and rocket plume studies.

The cell was designed for use with many state-of-the-art diagnostic tools including acoustic sensing, real-time radiography, laser positioning systems, infrared and ultraviolet imaging, and high-speed video.

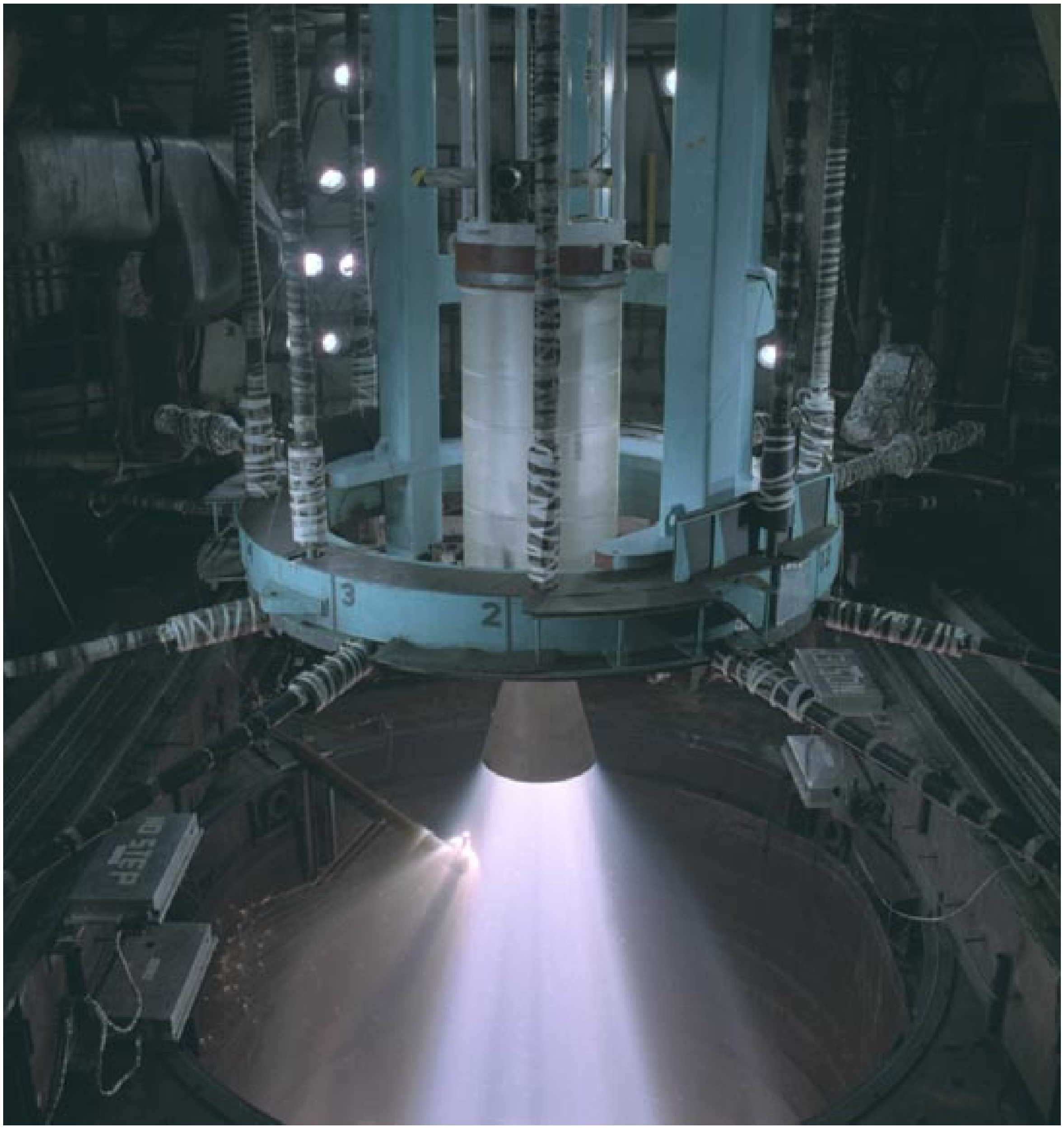


A Peacekeeper Stage II is loaded into the J-6 test cell.

Test capabilities of J-6 include:

- long-duration altitude tests
- testing of high-area-ratio nozzles
- altitude performance tests
- ignition performance tests
- spin testing
- nozzle development testing
- stage separation testing
- heat transfer and posttest heat soak testing
- vibration and dynamics testing
- failure analysis (propellant extinguished)

J-6 has been used to test Minuteman Stages II and III and Peacekeeper Stages II and III. It can be used to test many motors with either large quantities of propellant or with detonable propellants.



A Super Bates solid rocket motor being fired in J-4.

Analysis Tools

Successful acquisition of the desired information from simulated flight testing at AEDC is supporting plume characterization studies by an ongoing analysis and evaluation (A&E) capability development and demonstration program and a complementary technology development program.

Both of these programs are focused on equipping AEDC to better meet customer needs by identifying new or future test and evaluation requirements and developing the capabilities required to meet those needs.

The A&E program is primarily involved with identifying, developing and demonstrating new tools and techniques required to analyze test data and evaluate the performance of the test article. The technology program is focused on establishing enabling technologies to support the development and demonstration of new test instrumentation, advanced diagnostic techniques, state-of-the-art computational and modeling capabilities, and advanced testing techniques, in addition to identifying requirements for and supporting the design of new test facilities.

The A&E and Technology staffs at AEDC represent a broad range of technical expertise and professional experience which can be used to assist in addressing specific program needs. Advanced diagnostics and modeling,

(continued on next page)

simulation and analysis are examples of capabilities that can significantly enhance the value of simulated altitude testing at AEDC.

Advanced Diagnostics

Advanced diagnostics techniques at AEDC encompass a variety of applications such as advanced propulsion diagnostics, real-time radiography and acoustic sensor measurements.

The personnel who perform these operations are highly skilled, dedicated team members who represent AEDC on important advisory committees including NATO-AGARD, AIAA, JANNAF, and various Air Force and DoD steering committees.

Advanced propulsion diagnostics capabilities at AEDC consist of staff and electro-optical instrumentation devoted to the measuring of radiative signatures, exhaust gas pressure and temperature profiles, hot parts temperatures, species concentrations, flow-field velocities and aerosol properties in two-phase flows.

AEDC also maintains a large body of engineering codes and knowledgeable personnel who are accustomed to helping our customers solve difficult problems. These involve real-gas propulsive flows with chemistry, spray combustion, two-phase flows, molecular spectroscopy, and radiative heat transfer.

The instrumentation spans the spectral range from the vacuum ultraviolet below 200 nm to the far-infrared beyond 15 microns, and includes lasers, spectrometers, radiometers and cameras.

The latter includes state-of-the-art infrared array cameras, unique ultraviolet cameras, gated image intensifier cameras and high-speed (6,000 frames per second) cameras.

Modeling, Simulation and Analysis

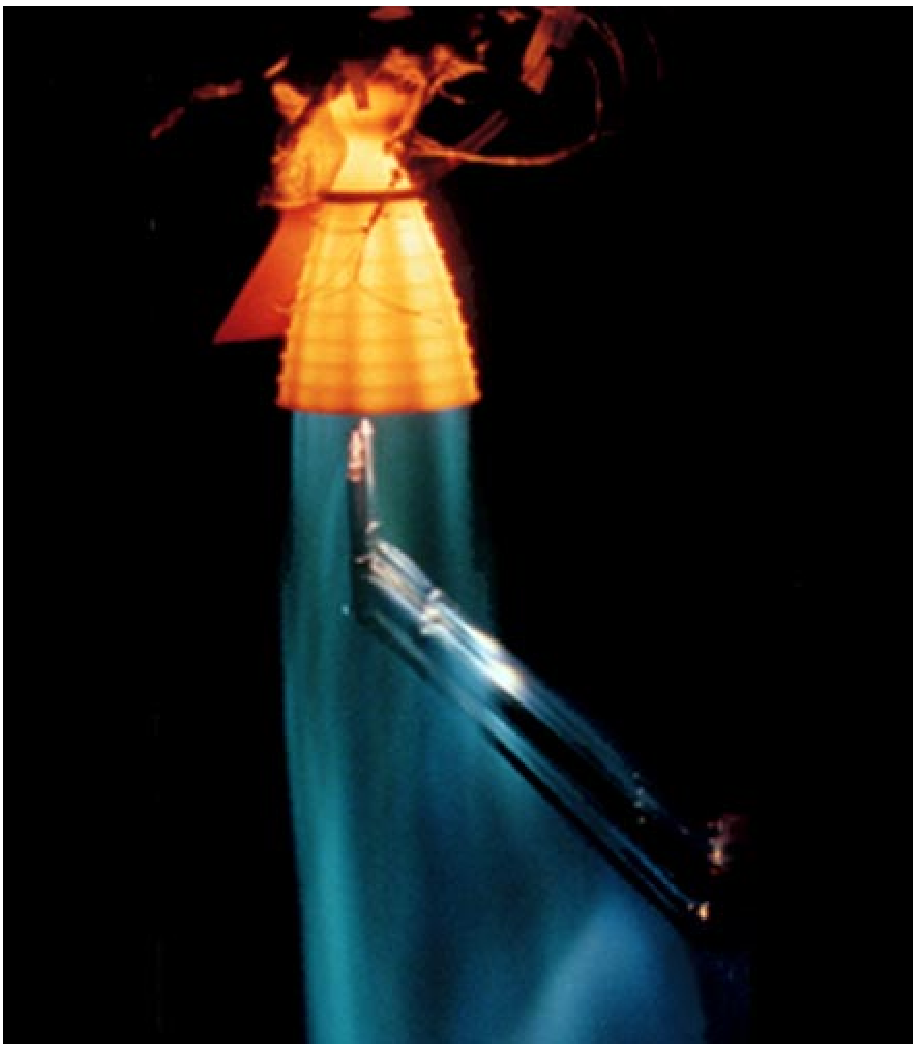
AEDC maintains an extensive library of state-of-the-art computer models applicable to support all areas of liquid and solid rocket testing.

Government standard computer programs that predict the spatial flowfield properties and the resulting steady-state thrust chamber performance (thrust, specific impulse, etc.) including quantification of inherent rocket performance loss mechanisms are an integral part of the computational library. The thrust chamber models supported include the latest versions of the Viscous Interactive Performance Evaluation Routine (VIPER), Two Dimensional Kinetic (TDK) computer program, the Standard Performance Program (SPP), and the Generalized Implicit Flow Solver (GIFS).

Interpreting nonintrusive measurements relies on the dependence of measured radiometric quantities (emission and transmission) to static temperature, static pressure, velocity, and the chemical species concentration present in the flowfield region of interest.

Government standard radiative transfer computer models for particle-laden, propulsion-generated exhausts are included in the computer model library. These include the Standard Infrared Radiation Model (SIRRM) and the Standard Ultraviolet Radiation Code (SPURC).

These models encompass the spectral regime extending through the ultraviolet, visible and infrared wavelengths, ranging from 0.2 - 25 microns. These models can also be applied to simulate the emitted signature of the propulsion exhaust. This information is used to assess the vulnerability of the propulsion system to threat sensors.



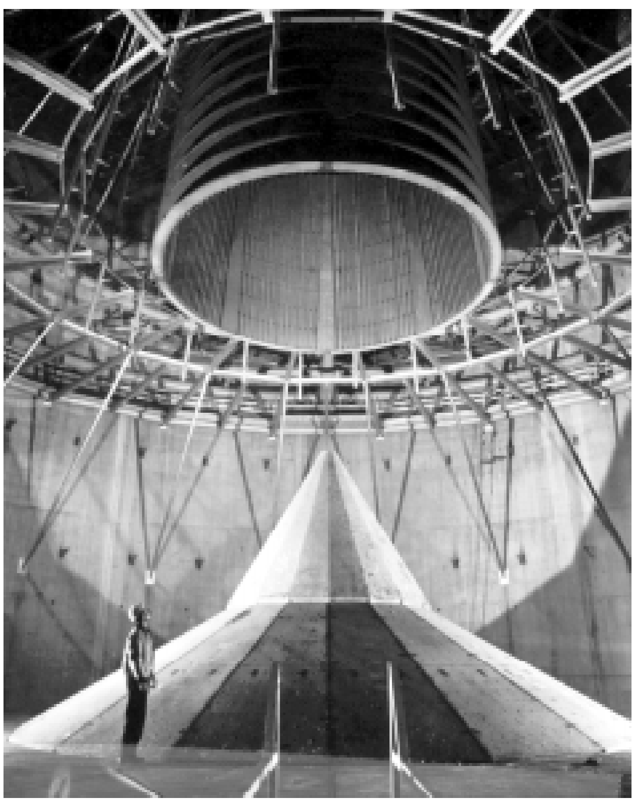
Boundary-layer pressure measurements on a small liquid-propellant rocket engine.

Hypergolic Liquid Propellant Supply Systems

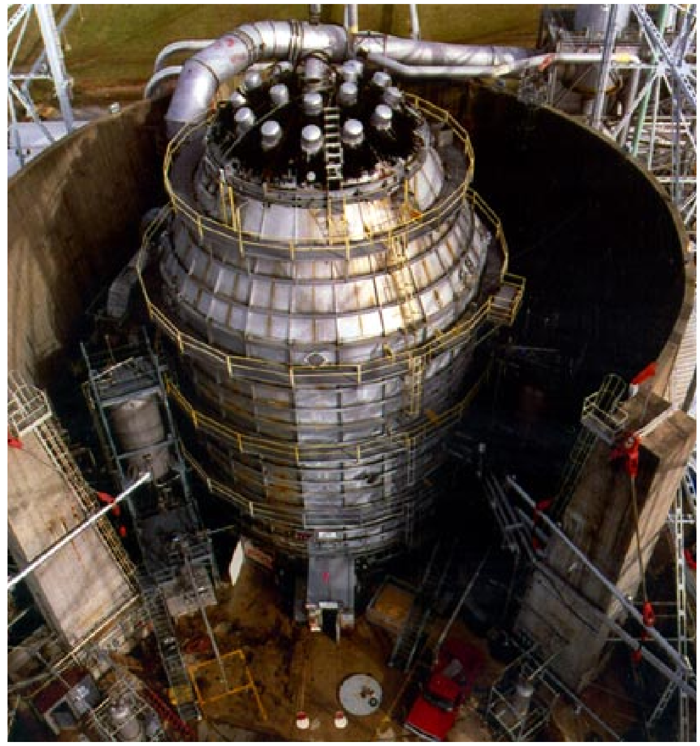
The Titan IV LR-91 engine uses storable, hypergolic liquid rocket propellants. The fuel (Aerozine-50) is nominally a 50-50 weight mixture of hydrazine and unsymmetrical dimethylhydrazine (UDMH), and the oxidizer is nitrogen tetroxide (N_2O_4). The hypergolic property relates to the ability to spontaneously ignite upon physical contact between the fuel and oxidizer.

The propellant system design consists of storage/run tanks and associated support structures, transport piping, safety spill pans, vent and purge provisions, and explosion proof electrical systems. A vacuum aspiration system was incorporated to remove residual propellant and vapors. Vapors were treated by the use of a scrubber system for the fuel and a flare stack for the oxidizer. The design also includes a propellant temperature conditioning system capable of maintaining a stable propellant temperature of 65 +/- 5 deg Fahrenheit (°F). Due to the toxic nature of these propellants, a state-of-the-art leak detection and alarm system accommodates the propellant system along with a local weather monitoring station to support propellant transfer and test operations.

The fuel and oxidizer system consists of a 7,000-gallon stainless steel tank located as close to the cell wall as possible to ensure the shortest pipe runs, and is designed to be filled from commercial tankers.



The bottom of J-4 test cell is 20 stories below ground



Bird's eye view of J-4 test cell.

Water Supply Augmentation

Cooling water flows are required in the J-4 spray chamber to cool and condense water vapor from the steam ejector and rocket engine exhaust flows before entering the ETF exhaust plant. Cooling water is also required to protect the steam ejector diffuser and exhaust flow deflector plate from the high-temperature impinging rocket exhaust gases, and to vaporize the liquid nitrogen (LN_2) used to render the exhaust gases inert.

Due to the specified extended firing time of the LR-91 engine (maximum duration of 300 second), additional cooling water capacity was required. The total amount required for a full-duration test was 2.27 million gallons.

The water augmentation effort consisted of constructing an additional 1.2 million gallon ground level water tank and piping it to the deflector plate and spray chamber supply line which was already fed by an existing 1.5 million gallon ground-level tank.

Additionally, the engine and steam ejector diffuser cooling line supplied by the existing elevated tank was tied to the underground 72-in diameter J-6 water feed line fed by the base water pumping system.

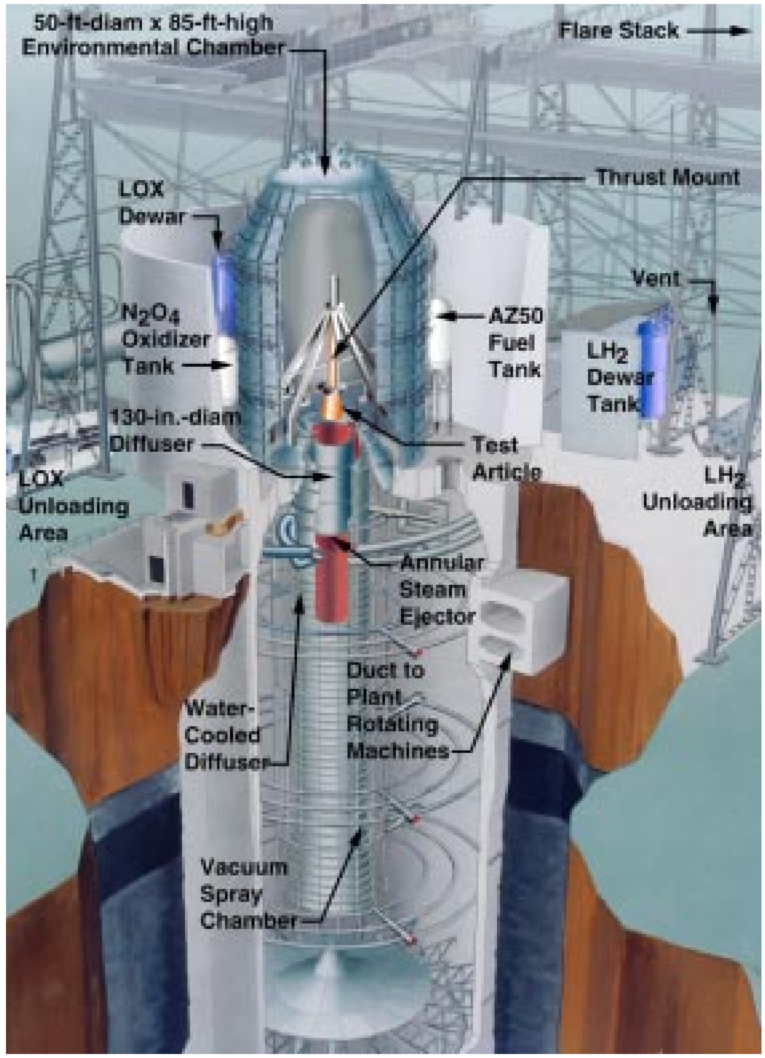
Modifications for Cryogenic Liquid Propellant Testing

Responding to inquiries for cryogenic liquid-propellant rocket engine testing, AEDC decided in 1993 to reactivate J-4 following a three year stand-down period and return it to a liquid propellant test configuration.

AEDC began design of a state-of-the-art cryogenic propellant system that would support testing of projected upper stage systems. Lacking specific engine and test criteria, AEDC used a "generic" turbopump-fed liquid rocket engine to set a design baseline capable of handling a nominal engine of 22,000-lbf thrust as a larger engine of 35,000-lbf thrust with mission length routines.

In March 1995, the Evolved Expendable Launch Vehicle (EELV) Systems Program Office selected J-4 as the test facility best suited for their upper-stage test support requirements and provided funding to complete the J-4 cryogenic propellant system upgrade with a scheduled IOC in July 1996.

Using these "generic" engine performance parameters, the cryogenic propellant supply and feed system was sized to accommodate 10,000 gallons of liquid hydrogen (LH_2) and 4,000 gallons of liquid oxygen (LO_2). State-of-the-art vacuum-jacketed storage vessels and run lines were designed and constructed. A graphical depiction of both the cryogenic and hypergolic propellant systems showing their relative locations at J-4 is presented in the top photograph. A discussion of the hypergolic system is given in the following sections.



Cutaway of J-4 with interchangeable diffuser insert.

Engine Diffuser Insert

The existing J-4 rocket diffuser system was optimized to test the Peacekeeper Stage II solid rocket motor which produces about 3 times the nominal exhaust mass flow of the LR-91 engine. The Peacekeeper diffuser was sized with an exhaust inlet diameter of 180-inch that transitioned to a throat diameter of approximately 130-inch diameter. With the test requirements calling for an LR-91 engine burn time of 300 seconds, an analysis of the existing J-4 diffuser was performed to assess its performance. This analysis showed that the existing diffuser would adequately maintain the required test cell pressure, but would break-down before the end of the 300-sec burn time due to its large exit diameter. Therefore, a new diffuser insert needed to be designed and built.

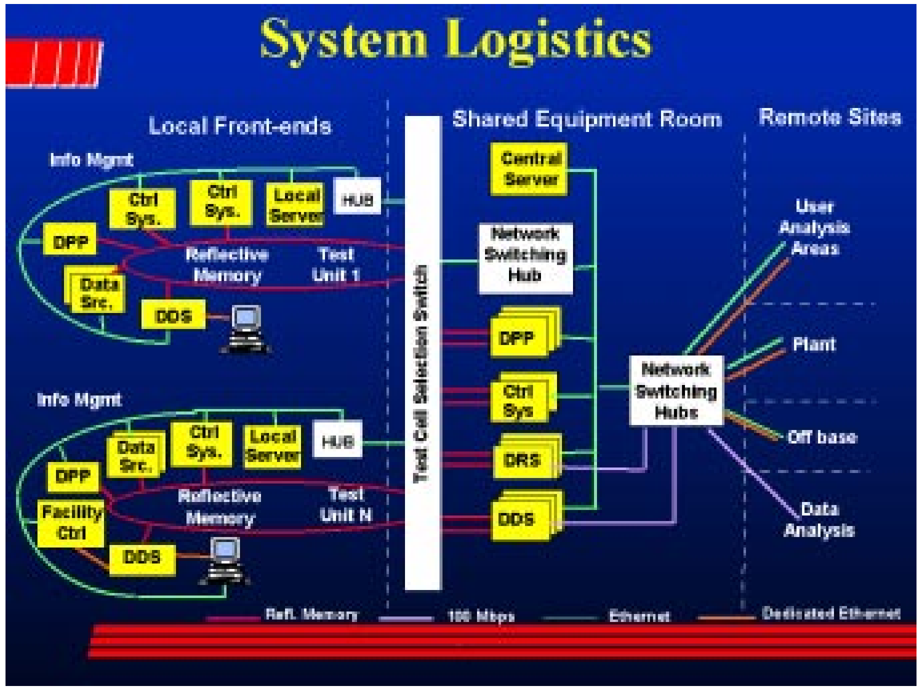
The new diffuser insert is a second throat configuration fabricated in three sections from PanlCoil®. The first two sections make up the diffuser's conical entrance. The entrance has a 130-in inlet diameter that tapers down to a 90-inch outlet diameter. The remaining component is a 90-inch diameter straight cylindrical section. Overall length of the insert is 486 inches.

ETF Data Acquisition and Processing System

To support customer-requested enhancements to the rocket test units data processing capabilities, AEDC is initiating the EDAPS (Engine Test Facility Data Acquisition and Processing System) project, a program to upgrade the data acquisition, processing and transmittal capability for test units J-4, J-5, and J-6. This system will double AEDC's rocket data capability from 250,000 aggregate samples per second to 500,000 aggregate samples per second.

The EDAPS program will support the latest in state-of-the-art rocket data acquisition. Some of the key features are the acquisition of thermal data using high resolution modular Digital UTRs, data acquisition from any independent data source such as the Military Standard 2553 electronic control bus or the AEDC PDCS3 high resolution pulse data acquisition system, an on-line calculated data display capability that can be reconfigured in real time, and data transmission directly to the mainframe processing computers over secure fiber optic links. The new system also allows independent operation of the other rocket facilities, eliminating the constraint to schedule calibration and data acquisition activities between the rocket cells.

All of these features are designed to enhance productivity while reducing constraints and turn around times between tests.



Engine Test Facility Data Acquisition and Processing System (EDAPS) data screen.

Future AEDC Facility Upgrades

AEDC is planning several future upgrades to the AEDC rocket propulsion facilities to accommodate the anticipated requirements for outyear DOD, NASA, and commercial programs such as the Evolved Expendable Launch Vehicle (EELV), Reusable Launch System(RLV) and validation of foreign component performance, and upgrades to existing space lift and strategic launchers.

Upper stage engines in the small, medium, and heavy lift categories are being evaluated for technology improvements or new applications requiring altitude qualification. These engines use cryogenic, hypergolic, or tri-propellants to optimize performance for the specific application. Examples of technology insertion include new exhaust nozzles, control systems, and materials to improve altitude operational and economic performance.

While existing propellant support systems are in place to test typical upper stage cryogenic and hypergolic propellant engines, new propellant delivery systems are in planning to support the heavy lift engine requirements.

These engines are estimated to be in the 200,000 to 800,000 lbf thrust category. Outyear plans for supporting these test requirements include additions of large engine cryogenic propellant systems, upgrades of the data acquisition system, increased integration of plume phenomenology instrumentation, and automation and optimization of consumable systems to improve system reliability and performance.

AEDC is planning other modifications including systems to support complete upper stage mission duty cycle testing. This includes provisions for mounting complete stage structures, engine gimballing, stage propellant delivery control and instrumentation systems, thermal conditioning, as well as loading, venting, and detanking systems.

All of these modifications are planned to maintain AEDC's position as the simulated-altitude test center of choice.

Related Facilities

AEDC is the nation's largest ground test center simulator of flight simulation test operating more than 50 separate facilities with altitude capabilities from sea-level to deep space conditions. In addition to rocket test cells, these facilities include space chambers, wind tunnels, arc heaters, ballistic ranges, nuclear effects facilities, and turbine test cells. Specific information on these facilities may be obtained from AEDC/DO or AEDC/PA. Of particular interest to launch vehicle developers are:

Titan IV fairing separation in MK I space chamber.

Environmental Space Chambers

Able to simulate deep space conditions up to 1.4 x 10^{-7} torr, AEDC space chambers vary in size to accommodate full-scale launch vehicle hardware as well as smaller components. MARK I, the largest chamber with a 42 foot diameter and 82 feet high, has been used for Titan 34D and Titan IV fairing separation tests, Small ICBM staging tests, and Minuteman penetration aids drop tests. The chamber can also be used to test space thrusters. Smaller chambers are used for smaller space thrusters, measurement of contamination effects, and verification of component-level mechanical and electrical systems.

Titan IV aerodynamic test in PWT 16T.

Space Shuttle in PWT 16T.

Propulsion Wind Tunnels

AEDC operates 16-foot supersonic and transonic wind tunnels and a 4-foot transonic wind tunnel. The 16-foot tunnels are equipped with a scavenging system to remove exhaust products when testing propulsion systems. The tunnels have been used to test launch vehicle aerodynamics, plume interactions with the airstream, and tactical missiles.

Arc Heater

Hypersonic Test Facilities

AEDC's uses a variety of hypersonic test facilities to assess vehicle performance. AEDC's aerothermal facilities are the highest-pressure arc-heated facilities in the U. S., providing unique, high-enthalpy environments for testing materials. Aerodynamic testing in the hypersonic regime is accomplished in Tunnels A, B, and C and in the Aeropropulsion Test Unit. The Hypervelocity Range G Facility can provide simulation of high stagnation enthalpy and pressures for ablation/erosion and aerodynamic testing of launch vehicle systems.

Advanced Missile Signature Center (AMSC)

The AMSC is a national archive of plume signature data for a variety of ballistic and tactical missiles. The AMSC employs a wide array of data analysis tools and JANNAF models to assess data quality and phenomena. Other resources include a complete video post-production facility and real-time video digitizing system, and a distributed computer system serving BMDO and SIPRNET classified networks.

Computer generated plume